AD NUMBER

AD466549

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 31 MAY 1965. Other requests shall be referred to Army Missile Command, Redstone Arsenal, AL.

AUTHORITY

AMC ltr dtd 12 Nov 1965

AD

REPORT NO. RG-TR-65-11

SIMULATION OF AN ATTITUDE DETERMINING SYSTEM UTILIZING MAGNETOMETERS AND EARTH'S HORIZON SENSOR

by
William F. Baxter

May 1965

U S ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA

DDC AVAILABILITY NOTICE

DISPOSITION INSTRUCTIONS

DISCLAIMER

31 May 1965   REPORT NO. RG-TR-65-11

SIMULATION OF AN ATTITUDE DETERMINING

SYSTEM UTILIZING MAGNETOMETERS AND

EARTH'S HORIZON SENSOR

by

William F. Baxter

Instrumentation Branch
Army Inertial Guidance and Control Laboratory
Directorate of Research and Development
U. S. Army Missile Command
Redstone Arsenal, Alabama

ABSTRACT

This report presents experimental data obtained by partial simulation of a missile attitude determination system consisting of magnetometers sensing the earth's magnetic field and a sensor responding to the earth's horizon. The contribution of various errors to system error is outlined. A basis is provided for possible future work concerning the effect of on-board interference.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1. Introduction

As part of its mission in the AMRAD program, the Army
Inertial Guidance and Control Laboratory was required to determine
the attitude of a spinning reentry body. One of the methods considered
was the use of magnetometers in combination with an earth sensor.
The AMRAD program was cancelled, but a portion of the effort relating
to this attitude determining system has been completed.

Although ancient, the use of the earth's magnetic field for azimuth
determination is still a common practice. It's use in the guidance
system of the German V-1 missile of World War II is probably the most
familiar of its applications in the field of missile guidance. Since that
time, interest has existed but has not been generally intense because
of problems of accuracy which will be discussed here. Although accu-
racy is the chief problem of the system mentioned, it was found that
relatively little information concerning magnitudes of system errors
was available. The effort in this laboratory to determine these errors
by simulating the system was the outgrowth of an attempt to calibrate
the magnetometers by use on the earth's field. It was noted that the
calibration device required most of the features necessary to simulate
the system. Therefore, the calibration equipment was constructed in
such a way as to also serve as simulation equipment.

2. Objective

The purpose of this investigation has been to simulate an atti-
tude determination system consisting of three magnetometers respond-
ing to components of the earth's magnetic field and a sensor responding
to the infrared radiation of the earth in order to examine the errors to
be expected with such a system.

3. Discussion

a. Definition of System Studied

The system studied (Figure 1) consists of three flux gate
type magnetometers whose sensing elements are mounted orthogo-
nally with one parallel to the longitudinal axis of a spinning missile, and
an earth sensor whose field of view is well collimated and parallel
to the sensing element of one magnetometer as shown. Since the tele-
metered data will, as the missile spins, show the points in time at
which the earth sensor responds to the earth's horizon, these points
may be bisected to obtain the time at which the earth sensor and mag-
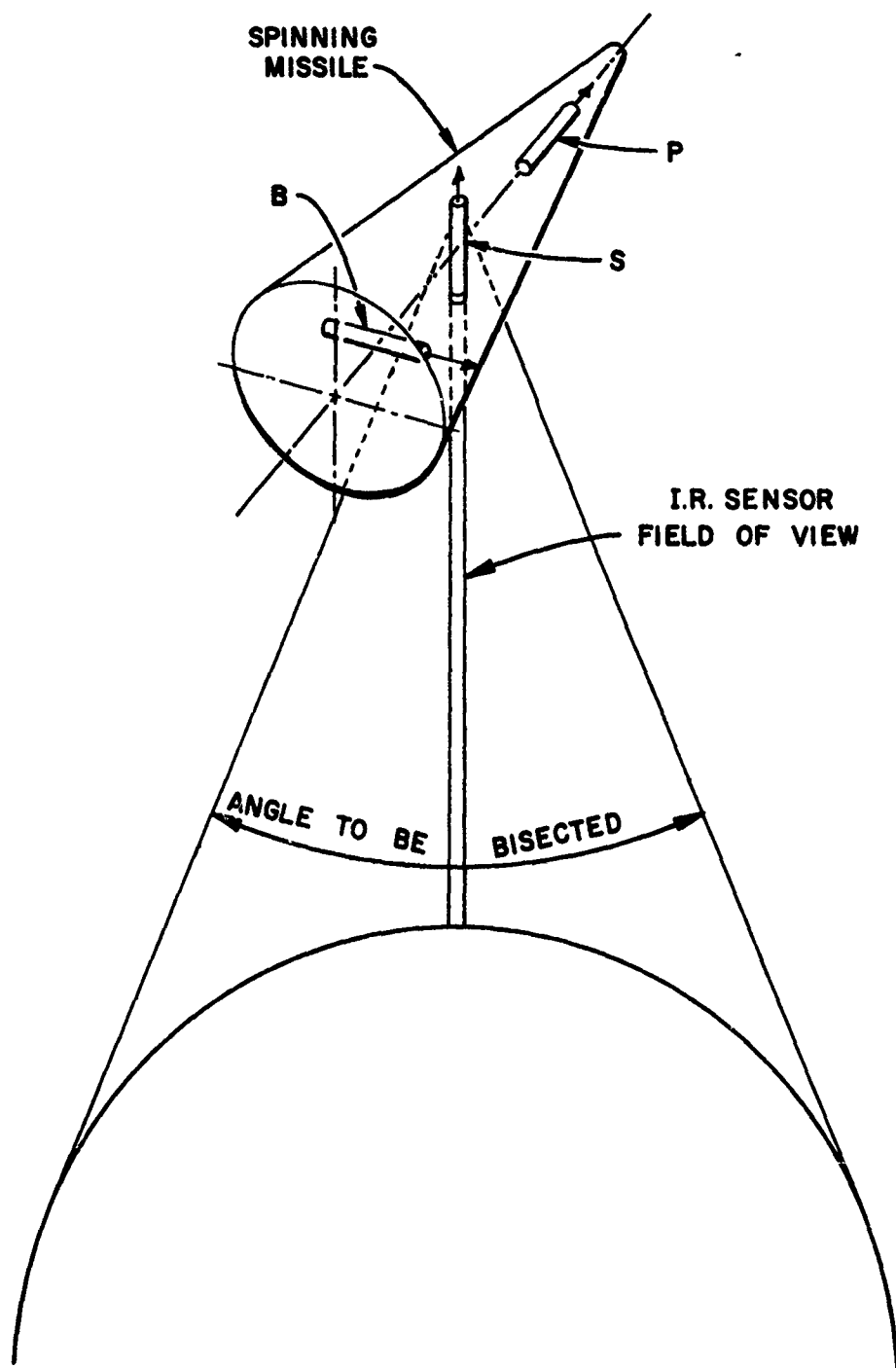netometers are in a vertical plane. At this time magnetometer B will

1

Figure 1. Magnetometer-Horizon Sensor System for Attitude
Determination

always be horizontal, and this is the point in time at which attitude determinations (azimuth and elevation angle of missile center line) are made. The system has aroused interest in the past, primarily because of its ruggedness and the fact that its operation is not affected by rather severe maneuvers or length of time it is in operation.

The flux gate type magnetometers used are very rugged and simple devices that give an output voltage which is a nearly linear function of the component of the magnetic field parallel to the sensing element. Therefore, with proper calibration the output of each magnetometer may be converted directly to the cosine of the angle that the sensor makes with the earth's field. Again referring to Figure 1, the elevation angle θ and magnetic azimuth ϕ can be obtained by using the three magnetometer readings and the dip angle of the magnetic field in the following expressions.

$$\phi = \sin^{-1}\left[\frac{-\cos B}{\cos b}\right] \tag{1}$$

$$\theta = 180° + \tan^{-1}\left[\frac{\tan b}{-\cos \phi}\right] - \tan^{-1}\left[\frac{\cos S}{\cos P}\right] \tag{2}$$

The quantity b is the dip angle of the magnetic field. The quantities cos B, cos S, and cos P are the direction cosines with respect to field direction of the magnetometer sensors which are read directly from the calibration curves. Expressions (1) and (2) are based on the three magnetometers being mounted in the positions shown in Figure 1, with the arrows indicating the field direction necessary to produce positive values for cos B, cos S, or cos P.

b. Simulator Device

The device used to simulate the system is shown in Figure 2. It consists of the three magnetometers mounted on a shaft (the shaft representing the missile) which is free to turn in roll in a box-like carriage. The carriage is free to be elevated in the vertical plane and the entire assembly may be rotated in azimuth on the round table. The azimuth and elevation angles are determined by using an ordinary nonmagnetic transit with standards and base separated as shown. Simulation of the earth sensor is not truly possible at this time since its input would have to be simulated also, and this input is not accurately known. It was decided to accurately determine the shaft roll position which the earth sensor determines and then insert assumed angular errors by offsetting in roll the shaft of the simulator by the amount of this assumed horizon sensor error. An effort was made to hold the error in the known orientation of magnetometers under test

3

in the 0. 1-degree to 0. 2-degree range, since mounting them in a missile to a greater accuracy can probably not be justified.

c. Errors of the System and Their Sources

If the mathematical expression for azimuth and elevation angle are examined, it is immediately evident that the ability of errors occurring in the magnetometer readings, cos B, cos S, and cos P to produce errors in the attitude angles ϕ and θ, is a function of these attitude angles. For example, we note that a fixed error in cos B will be much more serious when ϕ is near 90 degrees (missile pointed near due east) than when ϕ is near zero (missile pointed due north). A set of curves that will enable a person considering the use of the system to determine quickly the order of magnitude of errors to be expected at particular attitudes is the desired end product of the investigation.

(1) Earth's Field Direction. Inaccuracy in knowledge of the direction of the earth's field is a fundamental problem. If we are operating in an area where there is negligible local disturbance, the direction of the earth's field is usually considered to be known up to 100 miles or more altitude to within $\frac{1}{2}$ to 1 degree. It is, however, necessary to establish that there is no strong local disturbance. This is best done by making a number of actual measurements of the field direction at ground level in the general vicinity of the missile's trajectory. Since the values obtained from published charts are generally the result of considerable smoothing of observed data, good agreement between observed and chart values indicates that observed values are not the results of local disturbance. It is interesting to note that even if the chart values and observed values exhibit poor agreement, and if the general bounds of the local disturbance can be identified, some argument may be made supporting the use of the chart values at higher altitudes because the effect of a local disturbance drops off very rapidly with distance.

(2) Calibration Shifts of Magnetometers. The errors associated with the magnetometers derive from several sources. The things that will cause calibration shifts are chiefly variations in temperature, supply voltage, or magnitude of the earth's total field vector. It may appear strange that total field variation is considered as an error source since each magnetometer is actually measuring a component of this field. However, for reasons of convenience of calibration, the earth's field has been used to calibrate the magnetometers, therefore, a change in total field will produce a calibration shift and must be considered an error. Note that if no error is present and
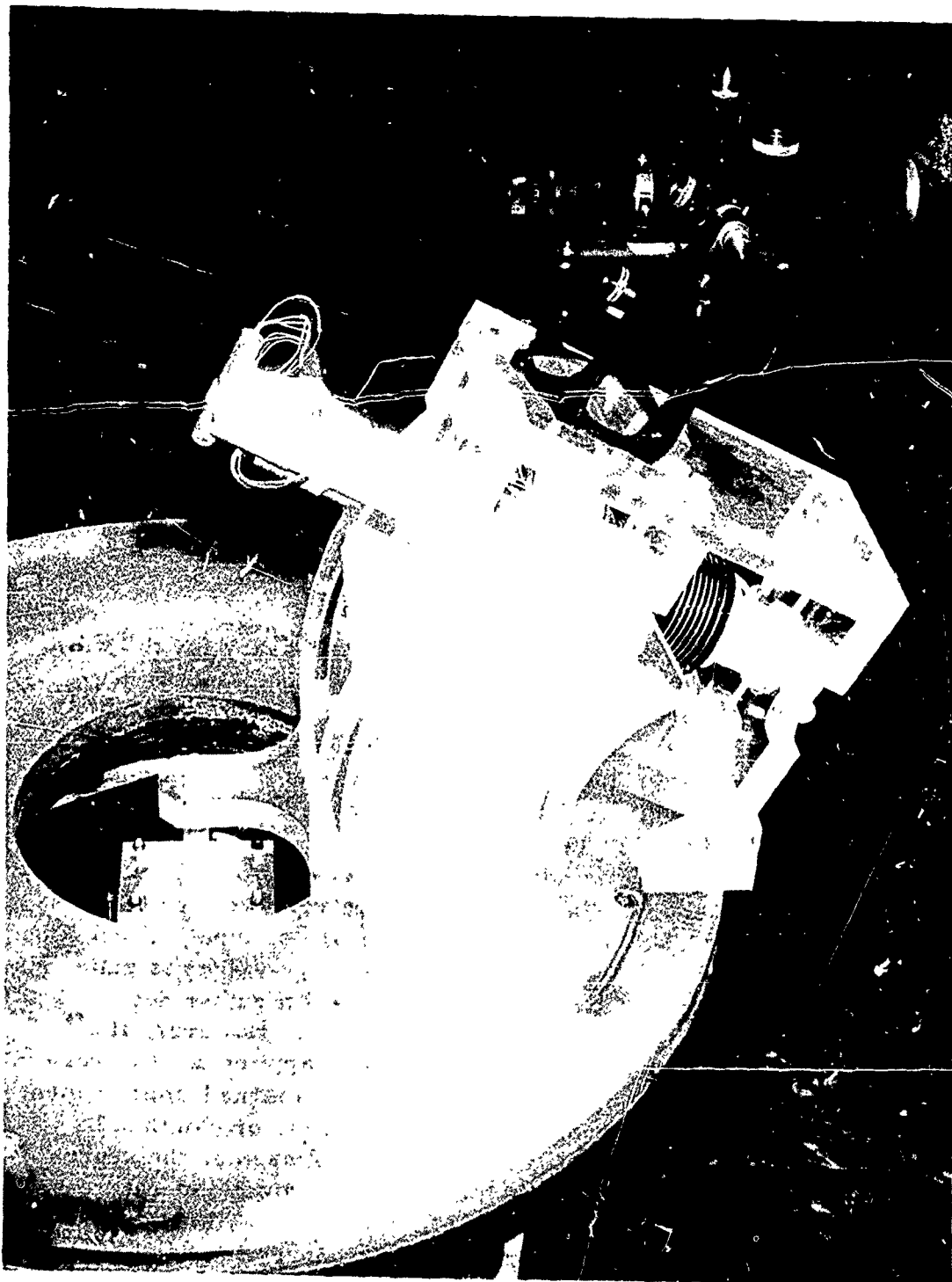
4

Figure 2. Simulation Device

since each magnetometer output represents the direction cosine of its sensing element with respect to the total field vector, the expression

$$\cos^2 B + \cos^2 S + \cos^2 P = 1 \tag{3}$$

must be true. If, since calibration, there has been a change in total field strength, since each magnetometer output is essentially a linear function of total field, and since the scale factor of the three magnetometers is essentially the same, this expression should be rewritten as

$$(c \cos B)^2 + (c \cos S)^2 + (c \cos P)^2 = 1 \tag{4}$$

where c is the correction factor which must be applied to each reading to bring it back to what the reading would have been under the conditions of original calibration. This correction factor

$$c = \frac{1}{\sqrt{\cos^2 B + \cos^2 S + \cos^2 P}} \tag{5}$$

must then be calculated and applied to each direction cosine before it is used to calculate attitude.

It is now noted that the general conditions necessary for the valid use of this correction factor are that the three magnetometers be affected in the same manner, and that for one set of environmental conditions the percentage change from calibration values of all magnetometer output readings be equal. The variations in output due to temperature and input voltage variations are now examined to see if they meet these conditions. Tests show that the first condition is usually met. However, examination of the curves showing percentage change in output for changes in temperature and input voltage (Figures 3 and 4) shows that for any particular temperature or input voltage change the percent change for several output voltage values is quite different. These curves at first appear to present a rather dark picture of a system based on these magnetometers. However, it is interesting to note that if the correction factor is applied as if it were valid, while the result is obviously not precise, a marked improvement in accuracy is usually obtained. This correction factor can then be applied to all magnetometer outputs regardless of whether the source of the original error was due to field strength change, temperature change, or input voltage change and, while the result will not be precise, it will usually be an improvement. This correction has been applied to all magnetometer data used in this investigation.
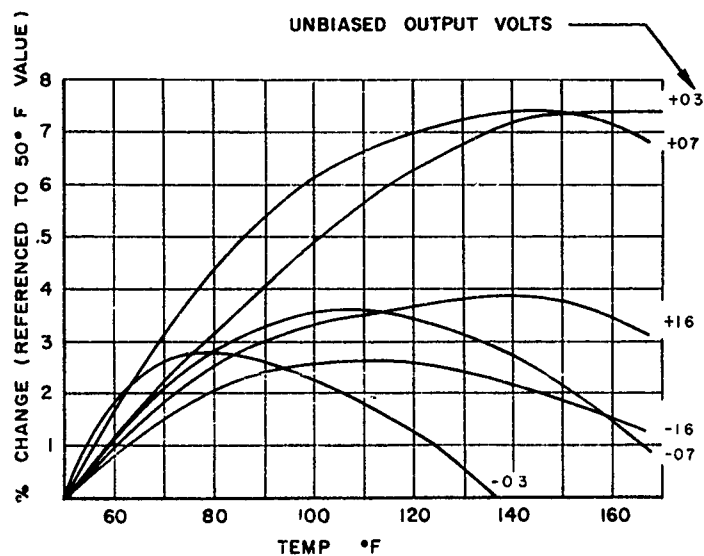
6

Figure 3. Curve: Variation of Output Signal with Temperature
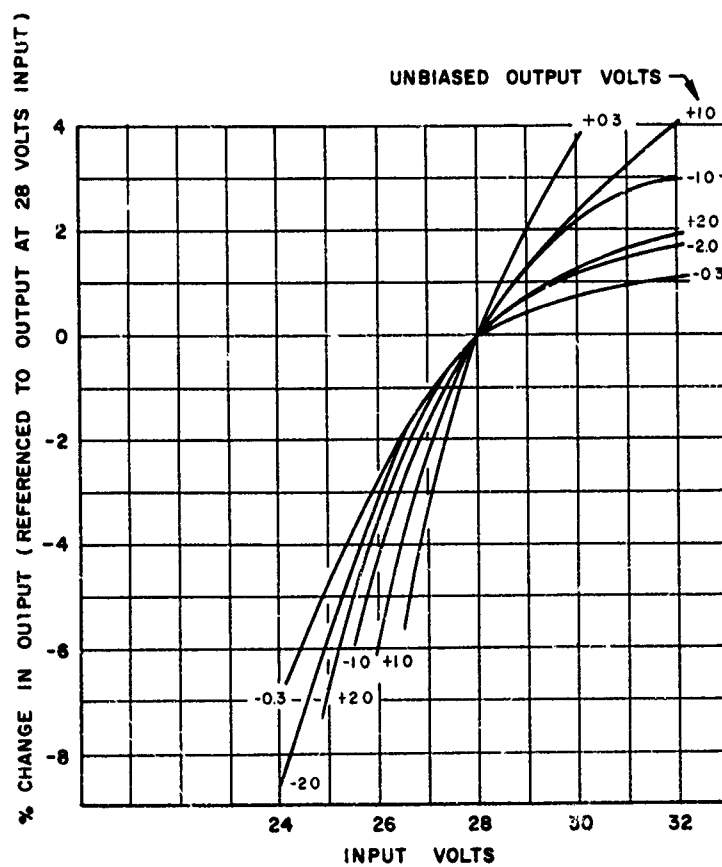

Figure 4. Curve: Variation of Output Signal with Input Voltage

7

In fairness to the manufacturer, it should be noted that since the purchase of the magnetometers tested, design changes have been made which are reported by the manufacturer to have greatly reduced the output variation with changes in temperature and supply voltage. If so, this improves still further the validity of the correction procedure described, and could in some cases eliminate the need for using a correction procedure.

(3) Onboard Interference. Any magnet or magnetic substance onboard will distort the earth's field and introduce error. The ideal solution is to reduce the onboard interference to the point where the problem is negligible, and this was the plan for its use in the mission mentioned previously. However, although no formal investigation of the problem has been made, it appears that it is possible to deal with a certain amount of onboard interference if the calibration of magnetometers can be accomplished while the magnetometers are actually in the flight position in the reentry body. This might be a rather ambitious undertaking, depending on the size of the flight vehicle.

(4) Horizon Sensor Error. The known attempts by several groups to determine what error can be expected in the vertical position established by the horizon sensor have met with great difficulty. The chief problem has been lack of applicable data. Considerable study regarding such problems at satellite altitudes has been done. The interest in the system discussed here has concerned its use at comparatively low altitudes where little study has been done. The estimates that have been made of the roll error associated with the horizon sensor at low altitudes range from 3 degrees down to less than 1 degree. As previously mentioned, the approach in this investigation has been to insert various known values of roll error and determine their effect on system error. As information becomes available regarding the horizon sensor error it should be possible to obtain the proper system error by interpolating between the assumed values used in this investigation.

Since the completion of the simulation work it has been reported that there is now underway an investigation of horizon sensors and the spectral distribution at the horizon for the altitudes of interest, primarily those up to 100 miles. Successful completion of this work may supply the information needed to make the interpolation mentioned possible. This reported work is within another government agency, and information regarding the stage of this effort has not been obtained at the time of this writing.

8

(5) Transmission Error. The chief remaining error is that resulting from the transmission of the telemetered data. In general, this error will be of the order of 1 percent for an FM/FM system or essentially negligible in the case of a PCM system. In this investigation the attitude has been computed both on the basis of hardwire measurements (this corresponding to PCM data) and on the basis of this same data after transmission over an FM/FM system conforming to IRIG standards.

(6) Built-in Ambiguity. As previously shown, the azimuth is calculated by an arc sine function. This function is double valued and is used assuming that the data reducer can choose between the two values equidistant from the East-West azimuth. The possibility of erring in this choice increases as the East-West azimuth is approached. However, as will be shown, the system error increases so rapidly as this region is approached that it is probable that the system would have been rejected for use at these azimuths prior to encountering the problem relating to this ambiguity.

d. Method of Test

The method of measuring errors used in this investigation was as follows. The test apparatus was set up at a point where interference from other equipment was not measurable. After determining the direction of the field, each magnetometer sensor in turn was placed in the slot paralleling the shaft axis. The shaft was then elevated to various positions in the vertical plane containing the field, and the position and output of the magnetometer recorded. A calibration curve was then made showing magnetometer output voltage versus the cosine of the angle between the field vector and sensor center line.

With the three magnetometers in their proper positions the shaft was turned to make magnetometer B horizontal, this being the position that would be established by a horizon sensor with zero error. A certain horizon sensor error was assumed and the shaft rotated off the position mentioned by this amount. The shaft and carriage was then elevated to some particular elevation angle which was measured with the transit. The entire apparatus was rotated in azimuth to various positions, and the output of all magnetometers and the actual azimuth and elevation angles were observed at each position. The magnetometer data were recorded after hardwire transmission (thus simulating a PCM telemetry system), and the same data were recorded after transmission over an FM/FM telemetry system.

9

Each of these groups of data was used to compute the elevation angles and azimuths of the shaft center line. In this computation it is necessary to insert the errors assumed to exist in the knowledge of field direction. Because of the nature of the tests performed it appears best at present to try to obtain the general bounds of expected errors rather than attempt to obtain information relating to statistical distribution of errors.

4. **Test Results, Observations, and Conclusions**

   a. Data Presentation Methods

As previously noted the desired results of this investigation is a set of curves that will enable a person considering the use of the system to determine the order of magnitude of the error under particular conditions. This information is presented in Figures 5 through 14. The curves consist of plots of error in computed true azimuth (and elevation angle) versus azimuth. The variation of error with elevation angle (the angle that the missile center line makes with the horizontal) is shown by providing separate plots for several values of elevation angle, namely 0, 15, and 45 degrees.

The effort to show the effect of varying several controlling conditions resulted in numerous curves. The following chart is provided to show the manner of their grouping and to serve as a key for locating the curve depicting a particular set of conditions. For example, the chart indicates that the set of curves based on $\frac{1}{2}$-degree information error (error in knowledge of the field direction), 2-degree roll error (horizon sensor error), data transmitted by FM/FM telemetry and showing azimuth error will be found in Figure 11.

Info. Error	$\frac{1}{2}°$							
Roll Error	1°				2°			
Data Type	HW		FM/FM		HW		FM/FM	
Error Quan.	AZ	EL	AZ	EL	AZ	EL	AZ	EL
Fig. No.	5	6	7	8	9	10	11	12

An additional set of curves, described later, is provided in Figures 13 and 14.

10

Figure 5. Curve: Attitude Error Versus Azimuth

11

Figure 6. Curve: Attitude Error Versus Azimuth

12

Figure 7. Curve: Attitude Error versus Azimuth

13

Figure 8. Curve: Attitude Error Versus Azimuth

14

Figure 9. Curve: Attitude Error Versus Azimuth

15

Figure 10. Curve: Attitude Error Versus Azimuth

16

Figure 11. Curve: Attitude Error Versus Azimuth   17
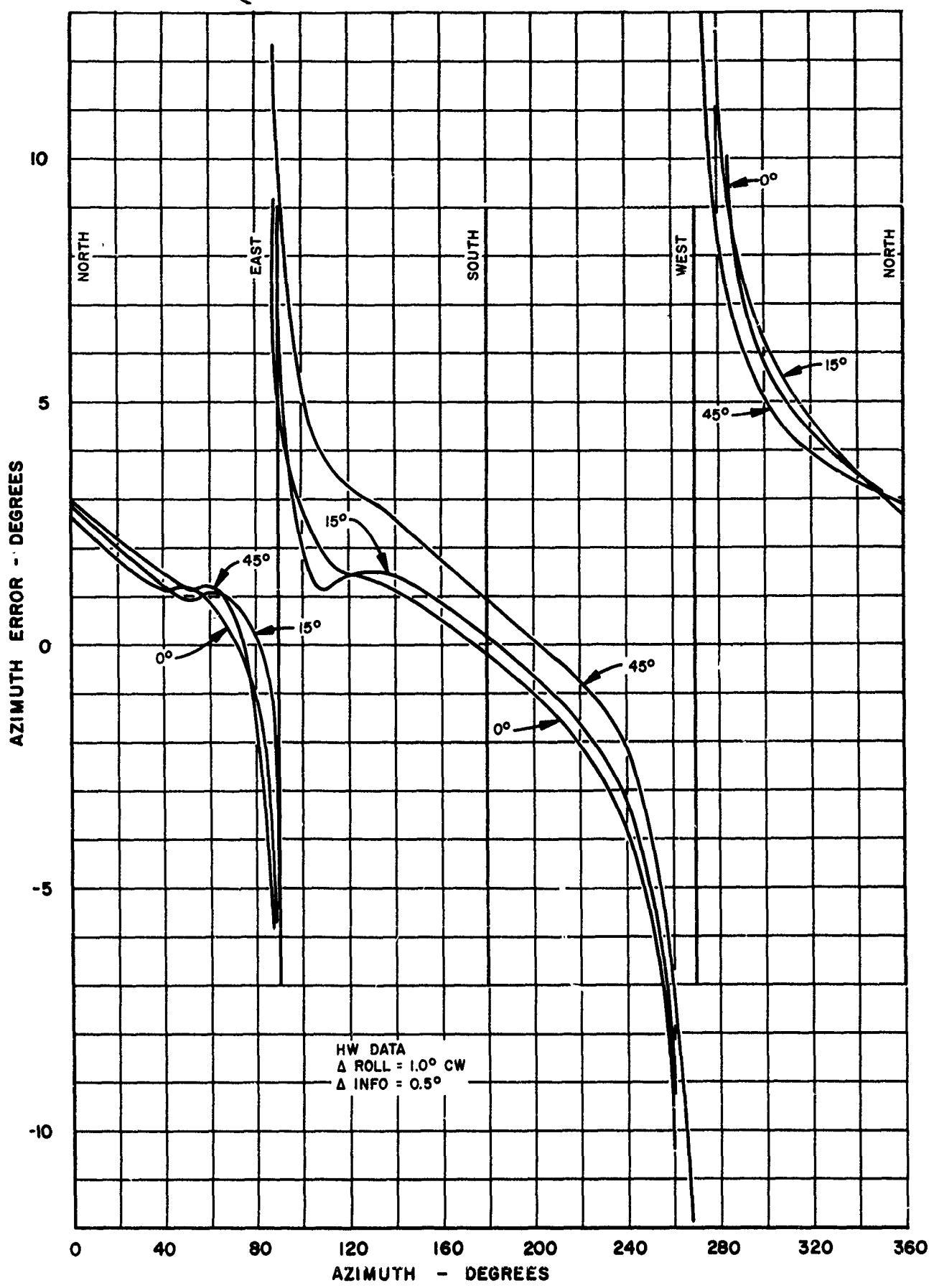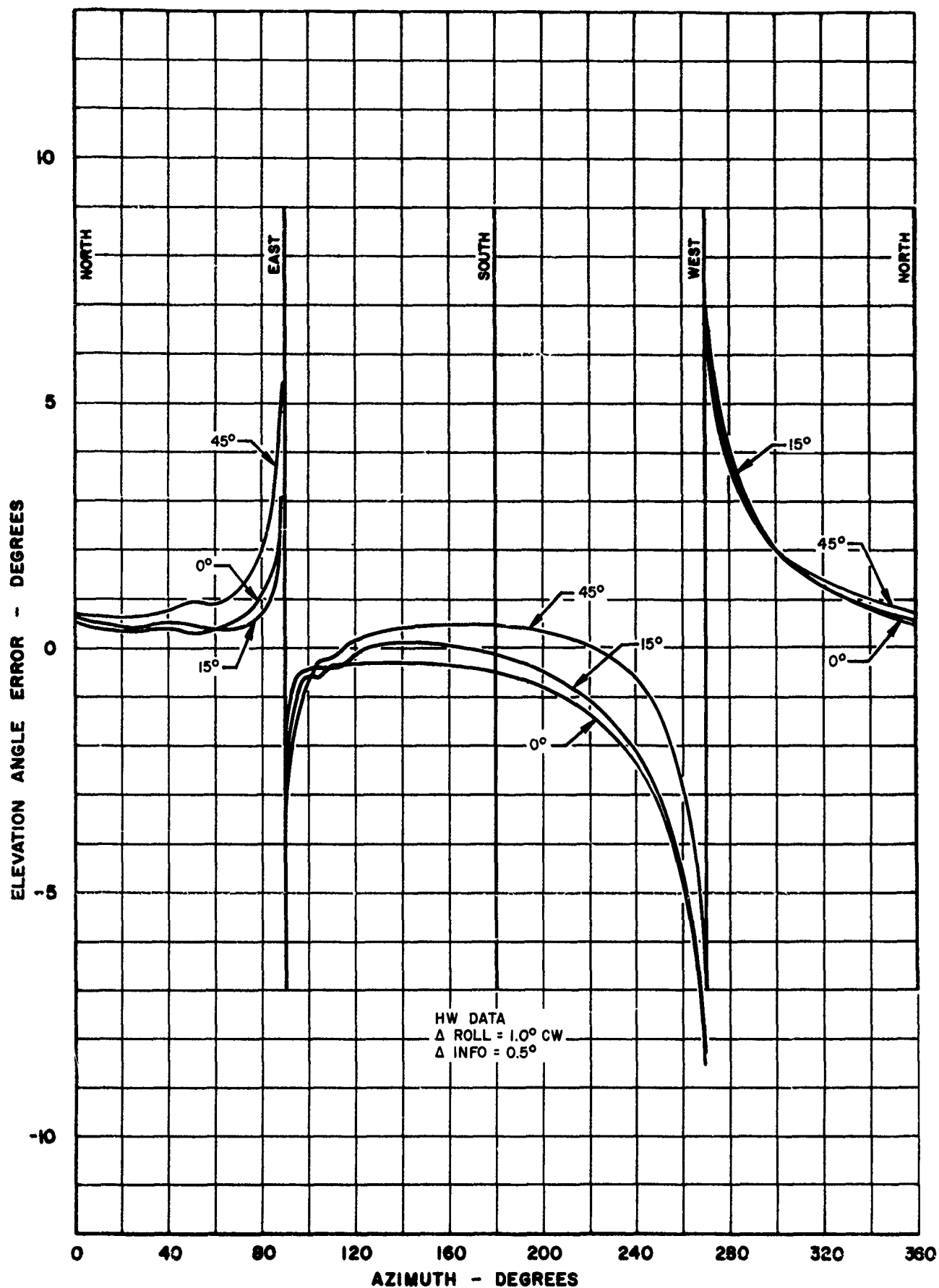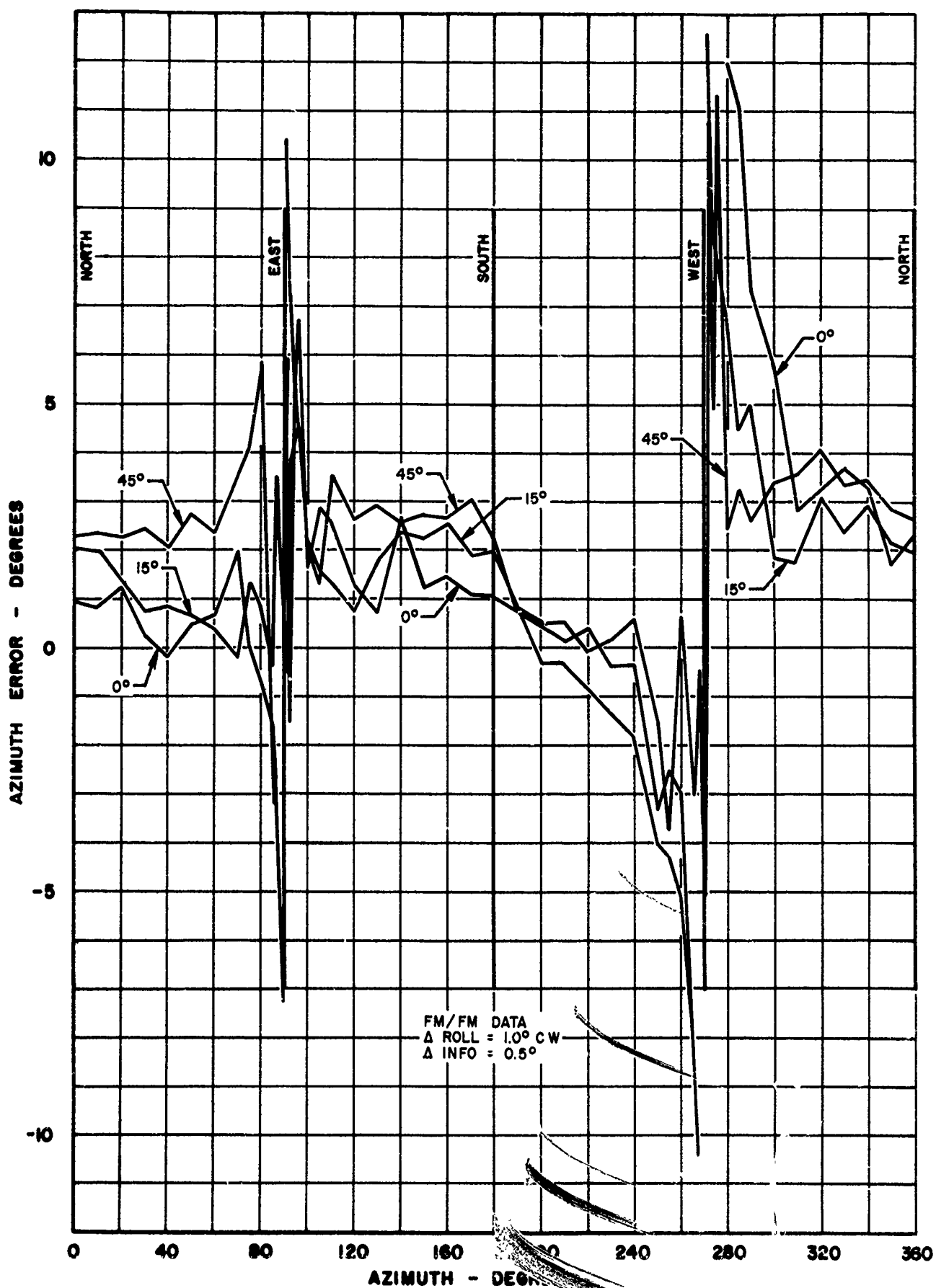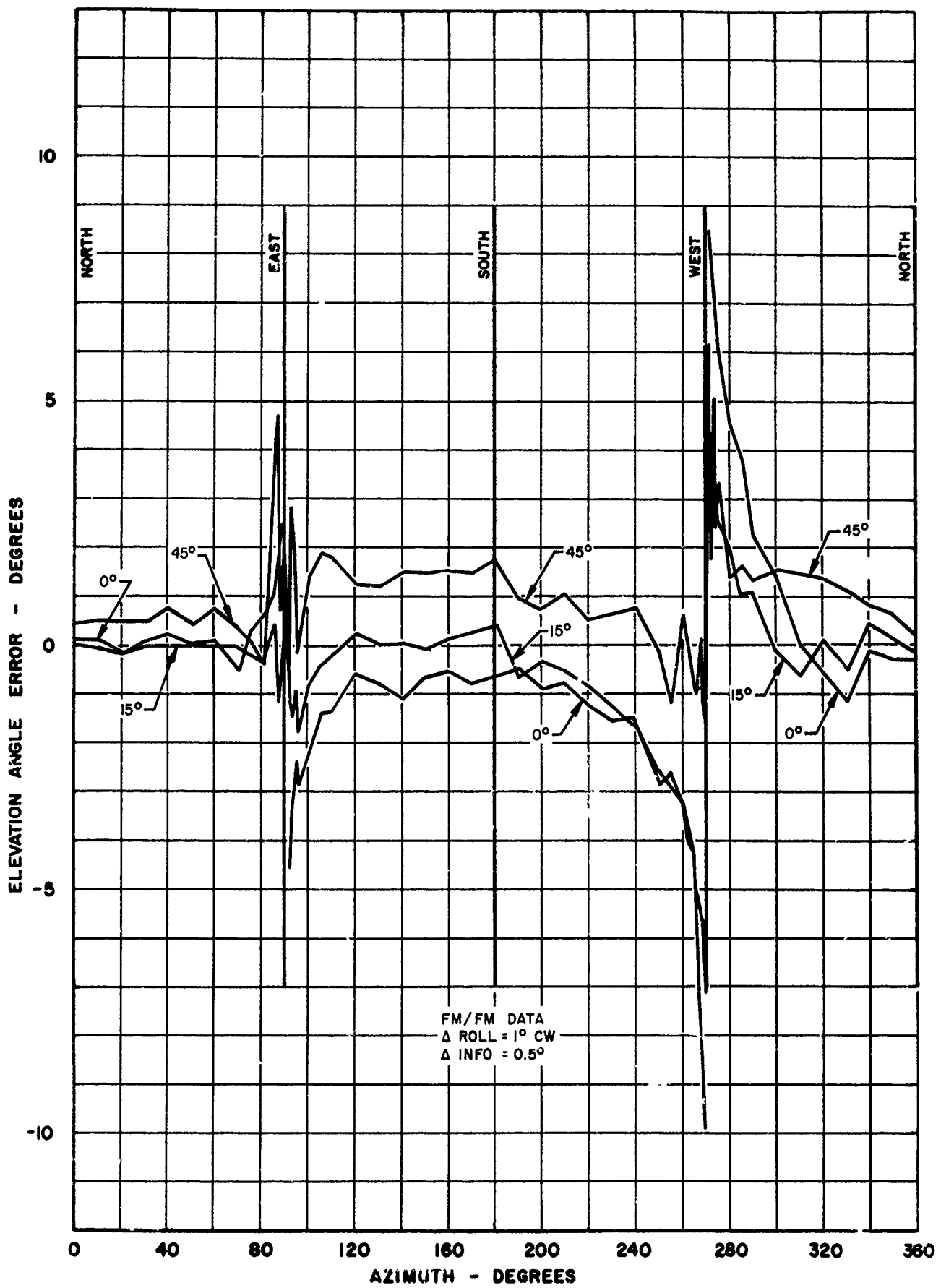
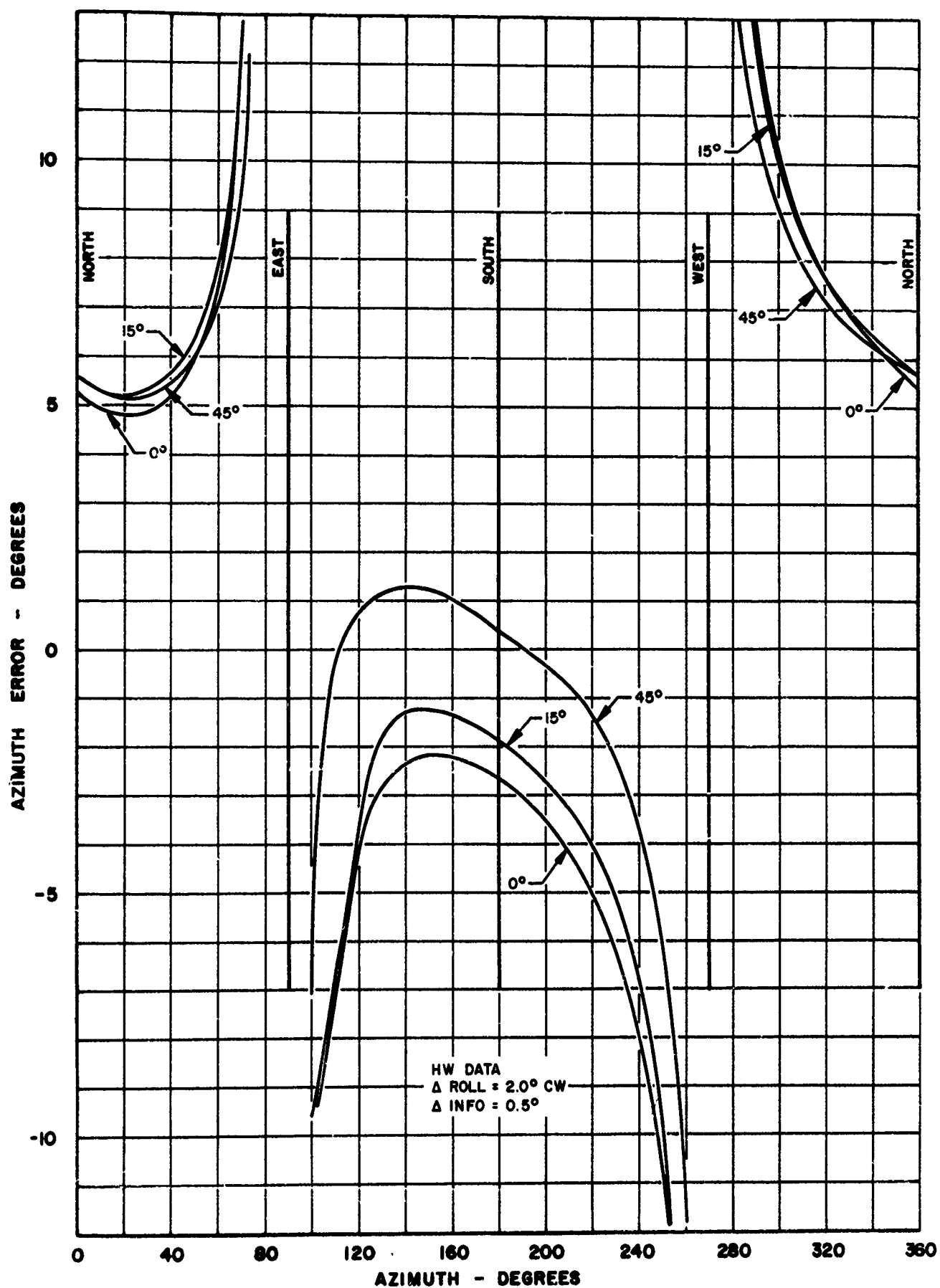Figure 12. Curve: Attitude Error Versus Azimuth
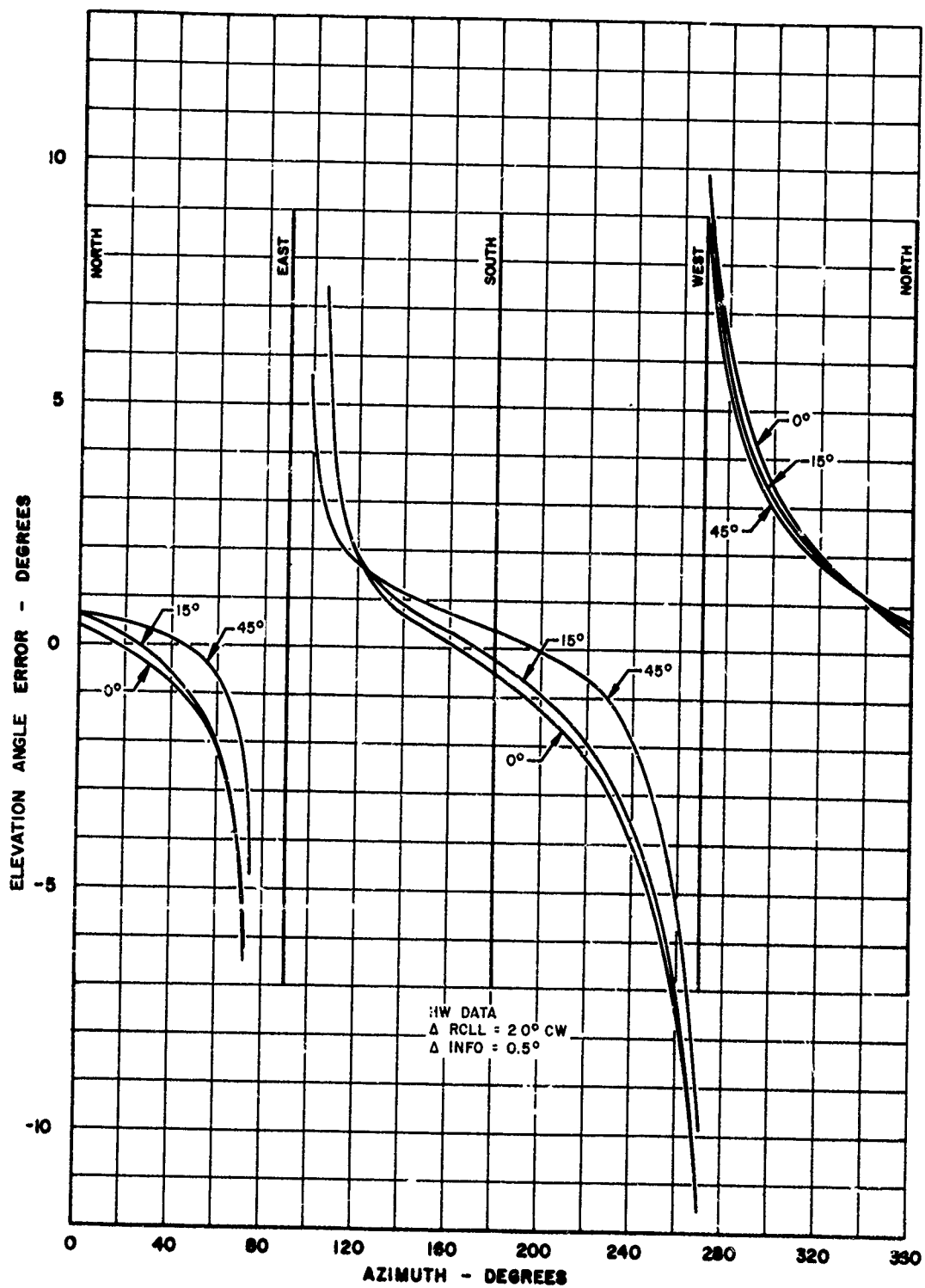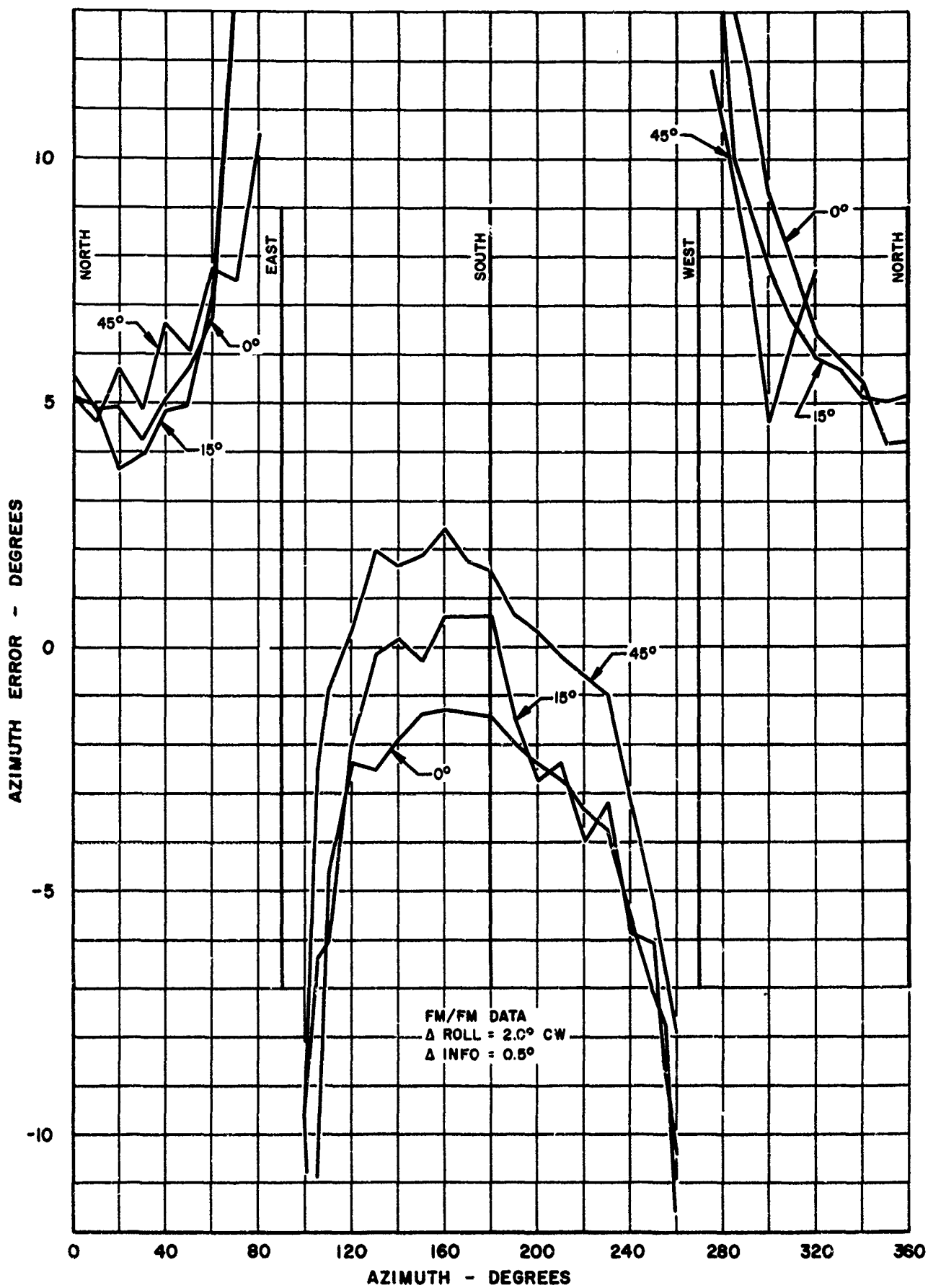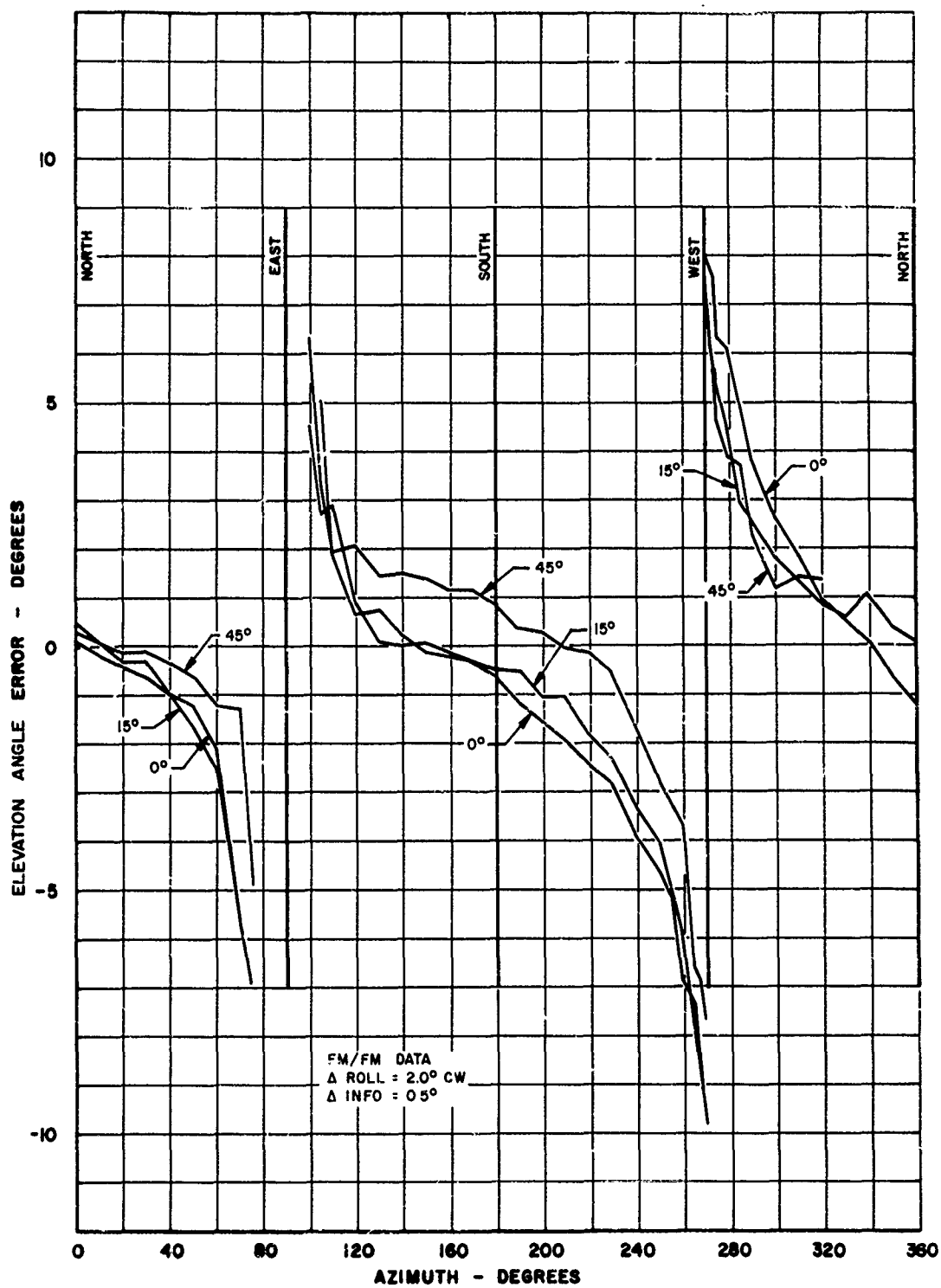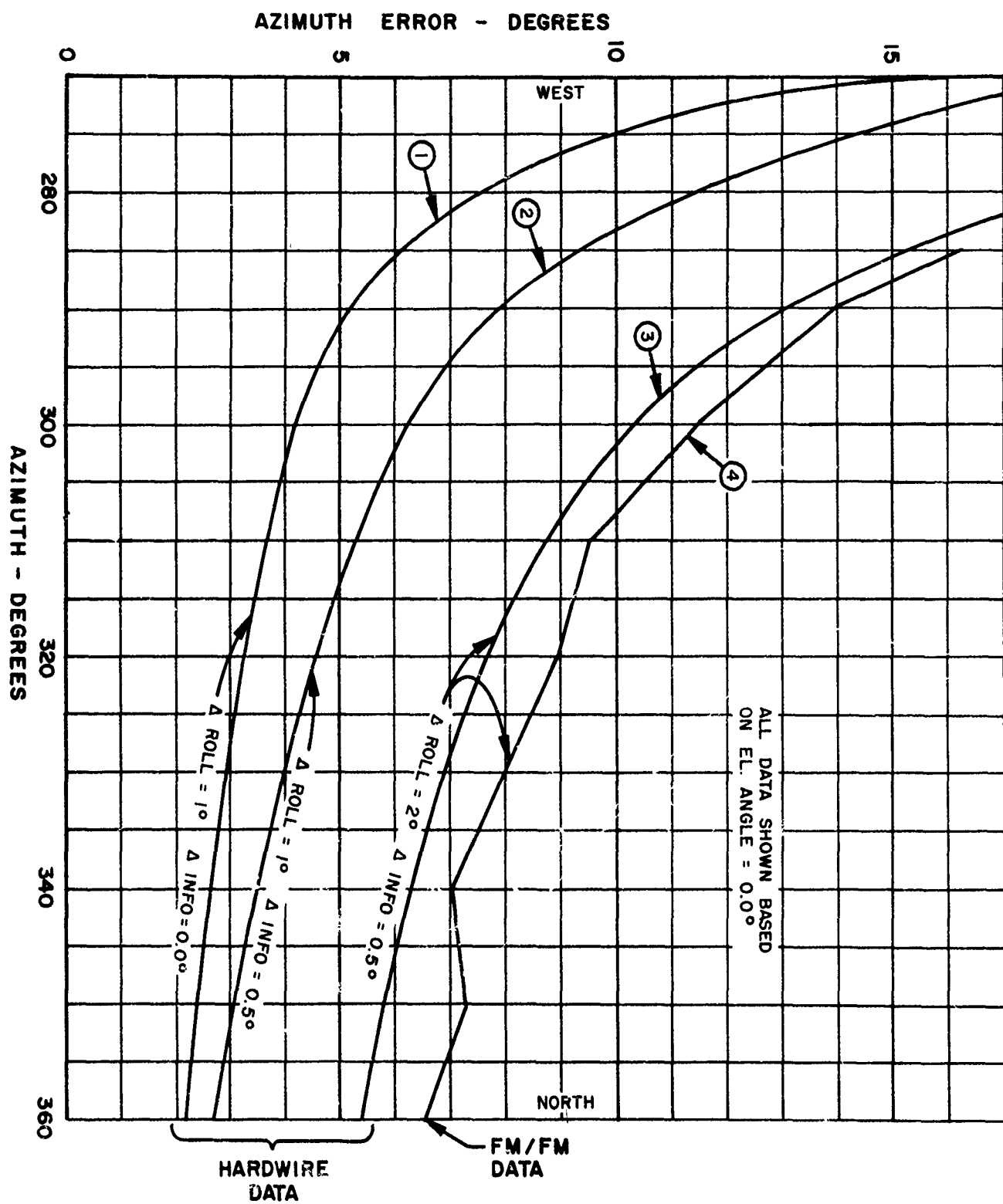
18

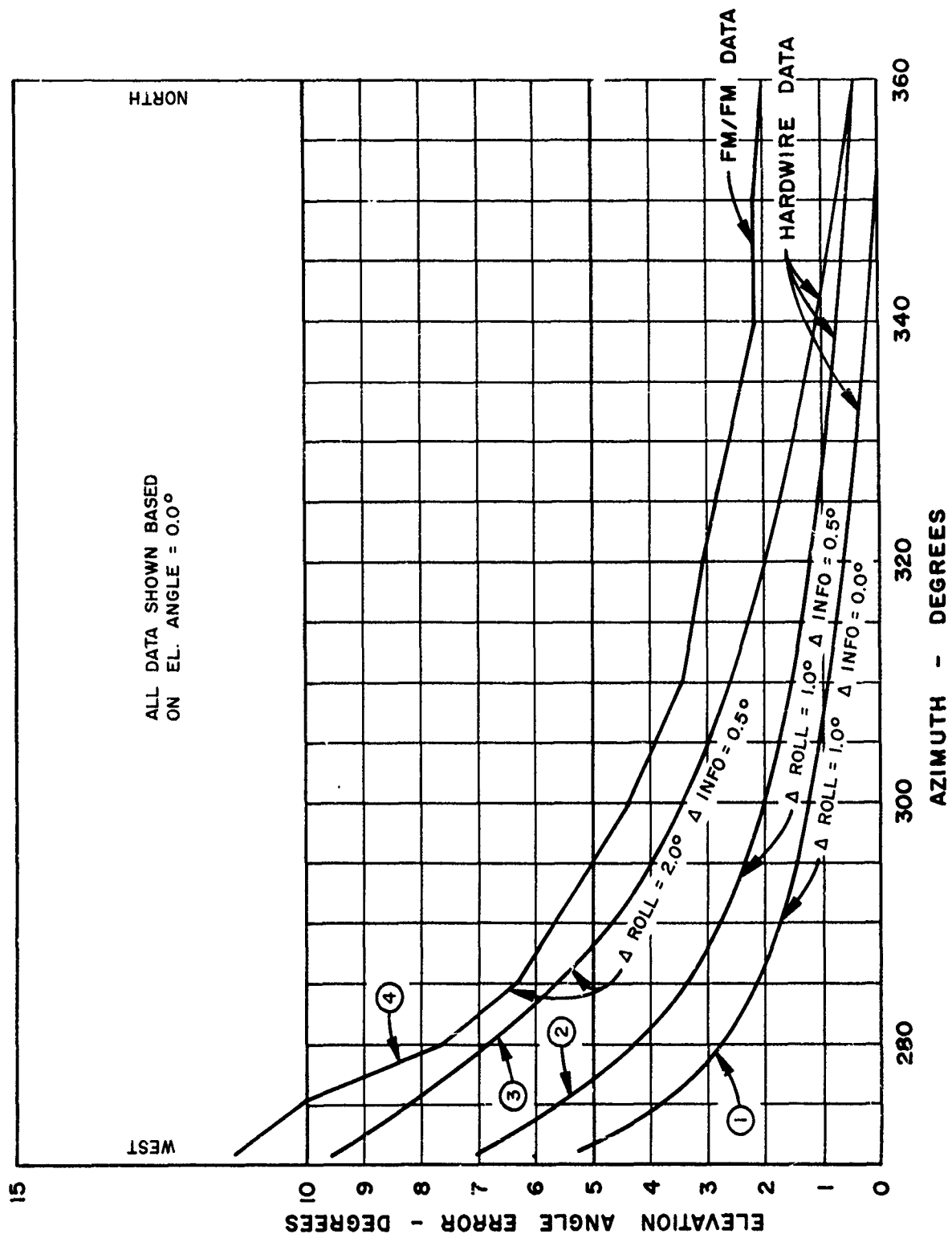Figure 13. Curve: Attitude Error Versus Azimuth

19

Figure 14. Curve: Attitude Error Versus Azimuth

b. Data Interpretation

The curves indicate the size of the errors to be expected
and how the pattern of errors is influenced by the contributing error
quantities. It is, however, necessary to keep in mind how the data
were obtained in order to make valid interpretations. The curves
indicate that the insertion of the contributing errors results in lack of
symmetry in the plots of system errors. There is no reason to expect
the contributing errors to occur in a particular direction, but it was
necessary to choose a particular direction for inserting the roll error
in the shaft position and to choose a particular direction for the error
in the direction of the earth's field. It appears possible that by proper
choice of error direction the portion of the curve indicating maximum
errors could have been made to fall in any of the four quadrants of
azimuth. It is therefore suggested that, if for example the error at
20 degrees azimuth is desired, the appropriate curve should be ex-
amined for the maximum value found at 20-, 340-, 160-, and 200-degrees
azimuth. A side effect (perhaps desirable) of this approach is that the
value obtained represents the error with either the positive or negative
value of elevation angle shown on the curve since the system error at
say 20-degrees azimuth and 15-degree positive elevation angle should
be the same as that at 200-degree azimuth and 15-degree negative
elevation angle.

It appears that a portion of the lack of symmetry noted may be due
to causes yet undetermined. To spot check curve values, reruns were
made with roll errors inserted in the opposite direction. Though this
produced different patterns of symmetry the system errors obtained
using the interpretation mentioned above agreed well with values
obtained from the curves shown in this report.

Also note that the curves based on FM/FM data differ from the other
curves in that the values shown are not necessarily the maximums to be
expected for the stated conditions. The values based on FM/FM data are
observed to be sometimes larger or smaller than the values based on
hardwire data. This was expected since telemetry error is of a random
nature. While a strong case favoring a treatment of these particular
errors based on their statistical distribution may be made, it is sug-
gested that, since the order of magnitude of errors is the chief interest
here, these curves be used mainly for comparison with the corresponding
curves for hardwire data. If, in the general vicinity of the attitude

of interest, the curves based on FM/FM data differ from the corresponding curves based on hardwire data by a maximum amount D and the hardwire data indicates an error of E, it is suggested that the quantity $|D|+|E|$ be considered the approximate error to be expected with the FM/FM system. The individual magnetometer readings obtained after FM/FM transmission were compared with the values obtained by hardwire, and the error due to FM/FM transmission of the data used for the curves did not exceed 1 percent of full-scale but fluctuated widely within that range. This is considered a rather typical range of errors for FM/FM data.

c. Observations and Conclusions

The curves indicate that in all cases the errors become quite large as the East-West azimuth is approached, thus precluding the use of this particular system if such attitudes are expected. It has been suggested that if such azimuths are anticipated, a similar system using a fourth magnetometer (or this same system with the magnetometers oriented differently with respect to the horizon sensor) might be feasible. Neither approach was investigated.

The curves show that while system error varies greatly with azimuth, the variation with elevation angle is comparatively small and often negligible.

The relative size of azimuth error compared with elevation angle error is interesting. For azimuths within 40 degrees of the North-South azimuth we note that for the most severe conditions simulated the elevation angle error never exceeds 2.5 degrees, while the azimuth error ranges up to about 7.5 degrees. Though interesting, this may not be particularly useful information since the accuracy requirement for both pitch and yaw determination is quite often the same.

It may be noted that some curves show widely different patterns of system errors although the contributing error values vary only slightly. An example of this may be seen in Figures 5 and 9 where the contribution of field direction error is the same, and the difference in roll error contribution is only 1 degree; however, the curves are not of the same general shape. It can be shown that whether a curve takes the general shape of Figure 5 or of Figure 9 is determined by the type of contributing error which predominates. Azimuth error curves of the type shown in Figure 5 are produced when the predominant contributing error is in field direction (information error). A linear and uncompensated shift in magnetometer calibration curves will also produce this type curve. Curves of the general shape shown in Figure 9 are produced when roll error is predominant.

22

Several of the curves indicate a severe lack of symmetry with respect to the zero error line. This is most noticeable in the curves showing azimuth error. This is apparently due to shifts in bias voltage values after calibration of the magnetometers. This voltage is provided by the electronics package associated with each magnetometer. As previously mentioned, design improvements are said to have improved the stability of the electronics of magnetometers manufactured since those used in this experiment. If these changes have improved the stability of the bias voltage, this would tend to reduce the size of the azimuth errors shown.

In order to better show the effect of the various contributing errors, a set of curves showing errors for one particular quadrant of azimuth is shown in Figures 13 and 14. The North-West quadrant was chosen since the data taken happened to show the maximum azimuth error in that quadrant. These curves indicate that the contribution of roll error to system error is very strong. It is interesting to note that an increase of 1 degree in roll error results in an increase in system error of 3 or 4 degrees. Since the roll error is also the chief unknown of the system, it appears that it will be necessary that additional information regarding this error become available before it will be possible to say that the system is or is not feasible for a particular mission.

The mission for which the system was originally considered was to have negligible onboard interference. This is a condition normally very hard to realize. Most flight bodies will have some interfering material onboard. The problem of dealing with this interference was not studied in this investigation. The general approach used in this investigation should be suitable for determining the feasibility of using such a system with onboard interference. Despite the fact that the present lack of information regarding roll sensor error prevents a true evaluation of the system error with or without interference, it is now possible to show whether the errors obtained with interference onboard can be made to approach those obtained in the investigation discussed here. In as much as any future use of the system probably will require it to accommodate some degree of interference, this appears to be the next step in any continuation of this investigation.

23

DISTRIBUTION

	Number of Copies
U. S. Army Missile Command Distribution List A	84
Defense Documentation Center Cameron Station Alexandria, Virginia - 22314	20
AMSMI-R, Mr. McDaniel	1
-RAP	1
-RBLD	5
-RGI	10

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY *(Corporate author)* Army Inertial Guidance and Control Laboratory Directorate of R&D U. S. Army Missile Command Redstone Arsenal, Alabama	2a REPORT SECURITY CLASSIFICATION UNCLASSIFIED
	2b GROUP N/A

3 REPORT TITLE

SIMULATION OF AN ATTITUDE DETERMINING SYSTEM UTILIZING
MAGNETOMETERS AND EARTH'S HORIZON SENSOR

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Progress Report

5 AUTHOR(S) *(Last name, first name, initial)*

Baxter, William F.

6 REPORT DATE 31 May 1965	7a TOTAL NO OF PAGES 24	7b NO OF REFS None
8a CONTRACT OR GRANT NO	9a. ORIGINATOR'S REPORT NUMBER(S)	
b. PROJECT NO None	RG-TR-65-11	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*	
d.	AD_____	

10 AVAILABILITY/LIMITATION NOTICES

Qualified requesters may obtain copies of this report from DDC

11 SUPPLEMENTARY NOTES None	12 SPONSORING MILITARY ACTIVITY Same as No. 1

13 ABSTRACT

    This report presents experimental data obtained by partial simulation of a missile attitude determination system consisting of magnetometers sensing the earth's magnetic field and a sensor responding to the earth's horizon. The contribution of various errors to system error is outlined. A basis is provided for possible future work concerning the affect of on-board interference.

DD FORM 1473
1 JAN 64

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
magnetometer flux gate FM/FM system PCM system attitude determining simulation						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

  (1) "Qualified requesters may obtain copies of this report from DDC."

  (2) "Foreign announcement and dissemination of this report by DDC is not authorized."

  (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through

                                                  ."

  (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through

                                                  ."

  (5) "All distribution of this report is controlled. Qualified DDC users shall request through

                                                  ."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C),* or *(U).*

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

26